PDC 2025
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Collisional Spin-Up of Asteroids: Alternative Mechanisms of Binary Asteroid Formation Independent of YORP Effects

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Keywords: Binary Asteroid Formation, Collisional Spin-Up, N-body simulation

The evolution of rotation rates of small asteroids is subject to mechanisms including: (1) the Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effect resulting in a net torque that can secularly modify the body's rotation rate and orientation; (2) off-spin-axis collisions by projectiles can change the spin state of an asteroid through the imported angular momentum; (3) planetary close encounters which can change the asteroid rotation state due to tidal torques. The relative importance of each mechanism depends on the size, shape, composition, structure, location in the solar system, and encounter geometry.

Some studies [1, 2] show that the YORP effect may gently spin up small asteroids close to and beyond their breakup limit, causing gradual mass shedding from their surface, YORP spin up has been measured over few decades, but the assumption of constant acceleration may not be valid over long time spans, for instance, in the Asteroid Belt, where impacts may change the asteroid local morphology and spin orientation. In the case of the NEA population, a recent study [3] showed that the degraded features on the surface of the primary of the Didymos binary system were more likely produced by

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impacts than by release of YORP-built surface stress. In fact, Didymos -like many NEAs- has part of its current orbit inside the inner asteroid belt, where they experienced several tens of DART-like impacts.

As an alternative formation process, a single collision, or a planetary close encounter, may abruptly spin up the body well beyond the breakup limit, causing sudden fission of the body. Such strong impacts may potentially cause sudden spin-up of the parent body above its spin barrier, potentially leading to a binary system.

[4] simulated the main belt asteroid collisional histories, showing that the well-known observed asteroid spin barrier can be reproduced by spin evolution from collisions alone, YORP is not required. Asteroids with diameters from 1 to around 10 km can be spun up to -and over- the spin limit by a few events, rather than by many small impacts. We study such processes numerically, modelling asteroids as gravitational aggregates with an updated soft-sphere-element-method implementation of the PKDGRAV N-body gravity code [5, 6, 7, 8] for the handling of non-spherical components. We developed a pipeline called SHattering EXperiments to Synthetic Shapes through PhotogrammetrY, (*SHEXSSPY*), to reproduce realistic angular shapes and the interlocking effect of the aggregate components.

We find that relatively large fragments and clumps may detach from the original body -triggered by impact or close encounter- and potentially evolve into a binary system, asteroid pair, contact binary, or simply be disrupted, depending on the collision conditions and transference of angular momentum. A significant part of the internal structure of satellites formed in this way may come from material well beneath the surface of the primary. This is likely different than in the YORP-induced binary formation mechanism. The upcoming measurements of the internal structure of the Didymos system components by the Hera mission (ESA) may provide insights into formation mechanism of binary asteroids.

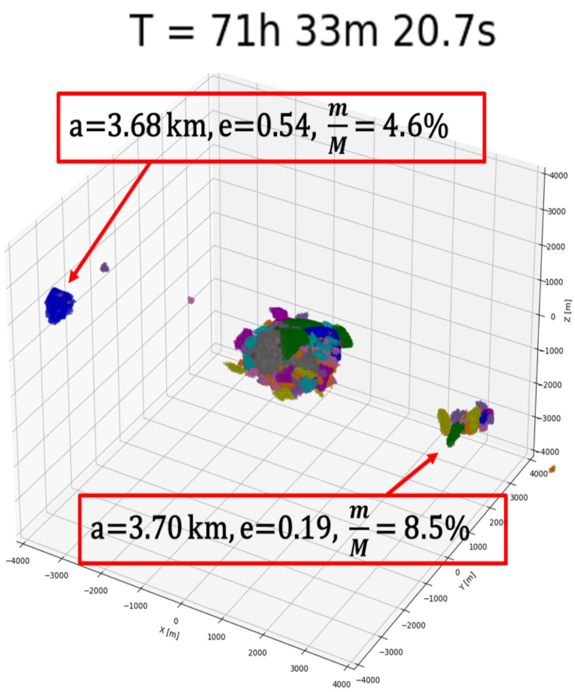

Figure 1: **Impact-induced fission of a 2 km size oblate (c/a = 0.5) asteroid, resulting in formation of two satellites. The satellite on the right has a contact binary structure, similar to the recently imaged secondary body (Selam) of the Dinkinesh binary system.**

Comments:

Our preference is to deliver an oral presentation; however, we are also amenable to presenting a poster if necessary.

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